Lifelike Robotic Collaboration requires Lifelike Information Integration

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Introduction

This paper is directed towards the definition of a systemic characteristic suitable for the "intelligent" core of a cooperative robot. A major issue in developing cooperative systems is the nature and degree of their autonomy. It is rare (rather, impossible!) that a communicated set of instructions for carrying out a task will be exhaustively complete, and with the passage of time the instruction set and the task's requirements often diverge. Neither complete dependence on control by a human "master", nor complete autonomy from control is suitable or desirable within such a context, but it is as yet unclear how a satisfactory context-dependent intermediate *modus* can be developed which is conducive to cooperation while not stifling any pre-existent or nascent capability for creative problem-solving. We believe that detailed examination of a number of more general aspects of system operation should predate attempts at defining performance measures for "intelligent" systems *per se*.

We wish to address four specific aspects of the performance and visualization of large information-processing networks. Firstly (1), the character of information transport through the networked connections of large systems; secondly (2), the way in which establishment of a hierarchical structure can alleviate some of the resulting problems; thirdly (3), the relationship between rationality and emotion within such a scheme; and fourthly (4), the manner in which information is integrated and visualized in human "thought" – which brings us right back to our first chosen systemic aspect (1).

Our starting point is the recognition that our environment cannot be completely described in any detailed manner by using a closed formal system of rationality. The representations we use for parts of our surroundings are all to some extent approximate in ways which relate to the varying nature of their interactions at different scales. Deviations from exact correspondence between descriptions of an entity at its different scales reside in the inter-scalar interfaces, where interactions are naturally complex and predictability is limited. As a simple example of this difficulty we can take a Boolean AND gate with 2 inputs and 1 output. Conversion between the 4 possible input states and 2 possible output states is controlled by the logical rules which correspond to the pre-defined gate function, but even so the gate's operation is irreversible because information is lost in the course of its operation. Reversible state compression demands the retention of *all* independent information, but the only way an AND gate can be made reversible is by recourse to non-local memory… more of this later. In the meantime we should simply note that wherever there is cross-scale information transport we can expect problems in the application of closed formal rationality.

1. Large Systems

Looking into the heart of a system, we often describe its pathways and their meeting points by the simple picture of a network of

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interlinked lines and nodes. An example is the ball-and-stick models which are used to describe molecules in chemistry. The balls represent not only entities, but also communicational nodes; the sticks represent major communicational pathways. If all of these pathways are similarly simply specified, whether as globally existing or globally absent, then the system is relatively easy to describe, and it can be referred to as being minimally complex. If, however, all of the pathways are individually specified, then the description is of necessity far more complex. We must also decide *very* clearly *where* we are looking at things from in painting our picture, as in reality we only have *one* point of view at one point in time.

A system can be described from an *external* platform as a set of "order parameters", where accessible characteristics are purely global ones, or from an *internal* point of view, where accessible characteristics are limited to local ones. It can also be described from *a quasi-external* platform as an externally viewed set of internal relations. This latter picture corresponds to just about *every* system analysis which we carry out, but unfortunately in a system which exhibits *real* scale effects internal detail is *inaccessible* through the application of formal rationality, or at the very least only approximately (although conventional science commonly presupposes this not to be the case - and no, we have not forgotten quantum mechanics here!).

So, our most usual "quasi-external" view is self-contradictory in non-formally-rational systems! We cannot equate the properties of different scales of an even marginally non-formally-rational system, or even arbitrarily change viewpoint within one and the same scale level without addressing the associated information transformations. Working from the simplifying presupposition that nearby viewing platforms will most resemble the one we are currently standing on, we will try to approach this problem by distinguishing between *directly* and *indirectly* accessible inter-elemental system connections[1]. *Direct* relationships are established by inter-elemental negotiation of both rationality and context, directly and intimately between the elements concerned, as shown in Figure 1. *Indirect* relationships between elements are those which of necessity pass through other intermediate elements, which may then be free to impose their own modifications on forwarded information: choice of the viewing platform imposes an asymmetry on the resulting view. This problem makes an appearance even in very simple systems: it is the basis of the difficulty most usually referred to as the Newtonian three-body problem.

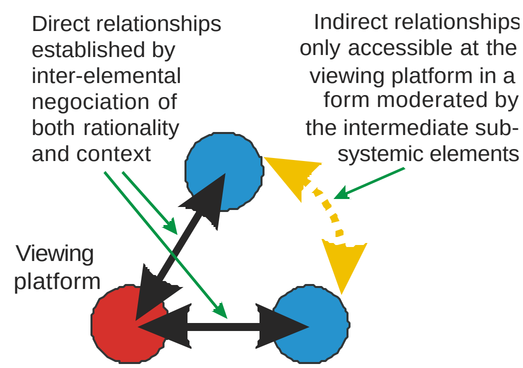

Figure 1. Direct and indirect relationships for a 3-body system with a chosen platform.

We can extend this distinction of direct and indirect linkages to larger ball-and-stick system models. Given 2 elements, we will have 1 direct link and no indirect ones; with 3 elements there will be 2 direct links and 1 indirect; with 4 elements, 3 direct, 3 indirect; with 5 elements, 4 direct, 6 indirect, and so on. As we move to larger randomly-connected systems the relationship between

[1] Clearly, the criticism we make here of "quasi-external" viewpoints can equally be applied to the argument we are ourselves presenting; but not, so far as we are aware, in a manner which leads ultimately to its destruction: we are trying to present a conceptual argument, and not a set of formally related parameters.

direct and indirect links takes on a clear form: the number of direct links goes up as the number of elements N; the number of indirect links goes up as the square of the number of elements $N^2/2$, as shown in Figure 2 (note that this effect is to some extent alleviated in scale-free networks [1], but that it never entirely disappears).

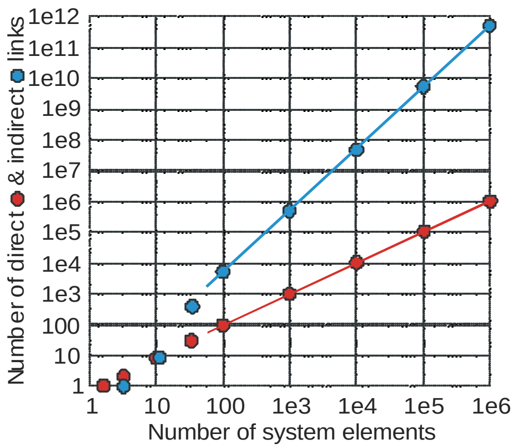

Figure 2. The growth of direct and indirect links in a large multi-element system.

The populations of direct and indirect character co-evolve at very different rates. For a system with one million direct links, there are a possible million-million indirect ones: for large systems indirect links are likely to dominate massively, depending on the complexity of the relationship between local and global structures. The character we can attribute to a complete system is ultimately *controlled* by this direct/indirect balance, as is the robustness of a network with respect to reductions in interconnection viability. The co-evolution of direct and indirect relations in large systems leads ultimately to two different independent systemic characters. One corresponds to the "normally scientific" view, which depends on formally-rational cross-scale information transport, the other corresponds to parts of the holistic system which are inaccessible to a "normally scientific" viewpoint, and which are associated with the distributed nature of indirect relations. Complete representation of systemic interactions with an environment requires the evaluation of *both* of these characters. If we simply describe a quasi-externally viewed system in terms of the reductively specified interactions we risk missing out *the majority* of the systemic character! (except if we are dealing with time-independent (clocked) artificial formal "machines" such as idealized digital computer systems). We believe that it is this bifurcation of systemic character into dual reductive and holistic parts, and the difference in rational accessibility between the two systemic characters, which has led to the conventional split between *body* and *mind*, where the body is automatically associated with direct "scientific" bio-systemic relations and the "mind" is naturally "difficult" to understand within the context of a "normally scientific" rationality which presupposes that all essential systemic aspects can be related to a single localized platform.

2. Hierarchical Stepping Stones

Large systems exist between two extremes: their unification as a single entity and the assembly of their smallest components. In any system, natural or artificial, where the spread in scale between these extremes is very large, intermediate self-supporting descriptive levels emerge (or are created) to facilitate transit across the entire scale-spread of the system (e.g. stairs, semiconductor inter-band traps, VLSI design, stars in the universe, …). This aspect of large systems is so pervasive that we can formulate a universal model for the resulting hierarchical systems [2] (Figure 3), whose properties are very closely tied in with the arguments of Section 1 above. Here each level of the coupled "model" hierarchy represents one and the same entity, for example a tree. Successive hierarchical levels describe the entity with a progressively changing degree of detail,

from the most elaborate to the most simple. For example: ..., a tree as atoms, a tree as molecules, a tree as cells, a tree as branches, a tree "as itself", … These successively simpler representations of the entity "contain" progressively more and more sub-scalar detail which is hidden from locally-scaled ecosystemic interaction.

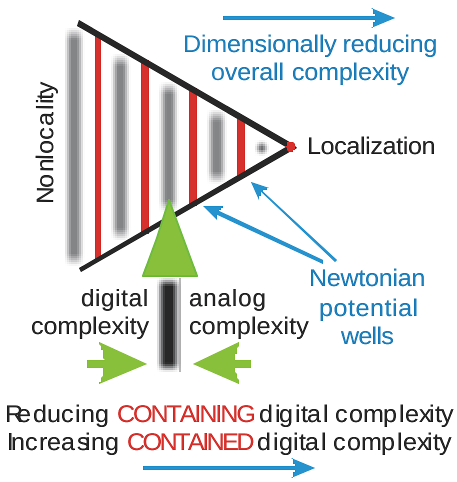

Figure 3. A generalized complementary hierarchical evolutionary system.

At a given level of the model hierarchy, the relevant representation provides a partial "en-closure" of sub-scalar detail, leading to simplification of the relationships between the entity and its locally-scaled environment as a trade-off against representational precision. Possibly the most important aspect of natural hierarchies is just this, that through the establishment of a series of related progressively abstracted models of low-level detail, high level "forms" are not constrained to operate within the complex temporal limitations of their low-level interactions. The apparently most simple model is the one which contains the most hidden sub-scalar detail. Within a computational paradigm this "hiding" of sub-scalar detail makes it possible for biological organisms to develop mechanisms for multi-temporally-scaled reactions to external stimuli, promoting survival in a complex hostile environment. Our own brains use a mechanism of this kind in the context of "fear-learning" [3].

The model levels appear as Newtonian potential wells in an otherwise non-Newtonian multi-dimensional and multi-scaled phase space between nonlocality (on the left) and localization (on the right) [4]. Moving between adjacent model levels, we encounter both kinds of complexity (digital and analog). Towards the left hand side of the assembly models are related to a global conservatism, and towards the right hand side to a local causality: the assembly forms a coupling structure between these two aspects of nature. Movement through different model levels towards the right corresponds to a reduction in the *containing* digital complexity of models and an increase in the *contained* digital complexity. It is worth adding that the Newtonian potential wells which correspond to the different model levels are regions of the universal phase space where global and local effects are self-consistent. This is a *fundamental* aspect of the stability and computability of nature. A major consequence is that, within these Newtonian regions, local causal interactions can proceed within limited temporal scales without fear of contravening a more global conservatism. However, the viability of such a structure as a general model of hierarchical systems depends on a fine balance between the isolation or "en-closure" of adjacent levels with respect to each other and the degree of inter-correlation which is necessary to support their stability and that of the hierarchy: a degree of inter-level correlatory information transport is *vital*: too much is fatal!

3. Ecosystemic Rationality and Emotion

The significance of the general hierarchical assembly we propose is that it represents the intermediate structure which we can

observe, not only between the complementary pair of "extra-real" nonlocality and "extra-real" perfect localization, but between and internal to *any* and *all* high-level "extra-real" complements. We can find complementarities of this kind everywhere as soon as we start looking for them: quantum and classical descriptions; organisms and their ecosystems; ... There is, however, a further *complementary* twist to the story. The hierarchical assembly we propose dissociates into two distinct and complementary systems of *rationality.*

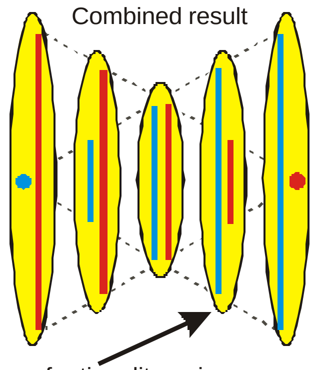

Figure 4. Interleaved "normal" and "complementary" rationalities in a generalized birational entity-ecosystem representation associated in local birational pairings.

One, of "normal" rationality, is associated with the Newtonian potential well model levels, and is reductive towards perfect localization. The other, of "complementary" rationality, is associated with the intermediate complex regions, and is reductive towards perfect delocalization [5]. The two systems are interleaved to give the complete structure which we showed earlier in Figure 3. It does not appear accidental that this binary complementary structure matches that of quantum-holographic vector-reconstruction information processing [6]. The result is a set of low-level local complements where a "normal" (local) level is always associated with a (local) ecosystemic "complement" level, as shown in Figure 4. The summation of both levels *at any scale* results in complete systemic description: the ecosystemic level provides a local but "normally inaccessible" store for all of the information which is eliminated through the "formally rational" compression to the current level through the stepping stones from the lowest level description (see the argument about a Boolean AND gate in Section 1). Interestingly, and probably unavoidably, this situation corresponds closely to the two sets of different information which are invoked during quantum error correction techniques.

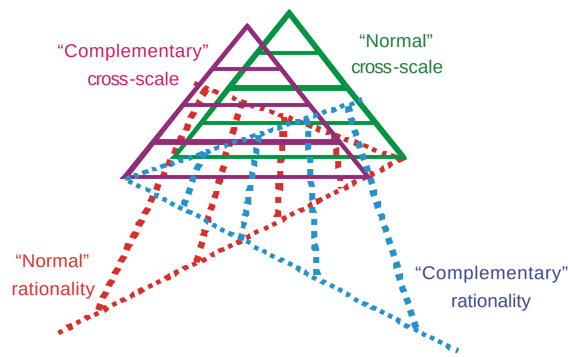

Figure 6. Interleaved "normal" and "complementary" multi-meta-scaled cross-scale rationality systems, based on their interleaved "normal" and "complementary" model assemblies.

We should remember that the Newtonian hierarchy must be globally stabilized by interactions right across the system between all scales. Noting that by "understanding" we usually imply "seeing the relationships between the level we are talking about and both higher and lower adjacent ones", we believe that inter-scalar interactions generate first a "hyper-scale" descriptive level, and then progressively a hyper-scalar hierarchy superimposed on the initial scalar one. A similar interaction for the "complex" hierarchy results finally in a *pair* of hyper-scale hierarchies, as shown in Figure 5.
It should be noted that at the highest hyper-scale levels, correlation between the developments of the two systems becomes increasingly less relevant, as the two structures progressively separate from each

other in association with the degree of their individual abstraction. At the highest levels, each of the hyper-scale manifestations is clearly and distinctly independent, and identifiable with a different kind of rationality [7].

This corresponds to the conventional picture we hold of our own thought processes; on one side there is a "rationality" which corresponds to scientific logic, on the other a very "difficult-to-categorize" but *effective* "irrationality" we refer to in terms of "emotion". The two are complementary: failure of (rational) logic in pragmatic situations can be circumnavigated by recourse (irrational) emotion; failure of an emotional approach can be rectified by the application of logic. Neither one can successfully exist alone: reason needs emotion, emotion needs reason. Our civilization habitually focuses on only *one* of the pair: reason is everything; emotionally, even, we feel we "should" be logical!

4. Information Integration and Consciousness

As we all (*sic*) were taught in school, the mammal eye works to create an inverted image of the viewed scene at the retina (whose orientation is rectified by the brain). Not so. There is no integrative capability at the retina to perform this function. Any "image" is generated much later, in the various layers and centers of the brain: it only "exists" within the (abstract) unification of high-level consciousness, and *never* in any "real" sense describable by science. If you are viewing this text via a computer screen or through the printed word, the same constraint holds: it does not exist *at all* as a unified entity outside your brain or imagination, merely as a collection of informational elements devoid of any *implicit* organization, which was transmitted through the Internet by a means which has been formally (scientifically) structured through the application of our imagination to achieve our aim of reproducing arbitrary "patterns" across space and time. The same argument holds for the *entirety* of our environment: it is *all* beyond representation by (current) science. Not only does this description apply to "objects", it applies equally well to any and every subject of discussion.

Most particularly, in the current context of interest, we should not expect to find that a robot is capable of responding as a "black box" to external stimulus on the basis of an internally integrated "motive", except where that "motive" is completely relatable to its formally unified degenerate representation – namely the binary "it exists" or "it doesn't"! Such a quasi-hierarchical relationship (along with any "algorithmic" complexity it exhibits) is both nominally and functionally trivial when compared to the styles of *real* complexly-hierarchical operation which characterize living organisms. We should consequently beware of attributing anthropomorphic integrative unification to the internal workings of a "black box" robot unless it is *entirely* predictable (a character which corresponds *exactly* to the quasi-hierarchical condition referred to above), in which case any resemblance of its actions to those of a human is far from likely, to say the least! So, can we describe and develop robots "in our own image" by the application of scientific techniques, or not? Or does the problem which must be addressed reside elsewhere?

Descriptions of the natural world and the placing of robots within it which derive from Evolutionary Natural Semiotics (ENS) by way of *signs* are untouched by this dilemma. In the context of ENS, any formalized representation is derived pragmatically (but less-than-algorithmically)

from its own scale-local grounding, and the various scale-localizations are coupled through and within the context of a global-to-and-from-local correlation which mediates between the scale-local groundings of a global grounding which it also creates (!). “Reality” (in a scientific reductionist sense) then refers to nothing more that the lowest level of description which we can be bothered to deal with, whether that be the atomic level, super-strings, membranes, people, trees or psychological states.

The descriptions which we habitually employ for “systems” which are internally structured in a network-like manner are suitable if, again, the network structure is amenable to complete (formal) integration *reductio ad adsurdum*, but for a “system” which exhibits “useful” complexity, they are worthlessly simple or simplified. Within ENS such representations (where we view the “system” as a whole and *simultaneously* its network-like internal structure) have the character of (dubious) quasi-external representations, whose (cautious) applicability depends primarily on their degree of representational equilibrium. Much effort is currently being expended in developing “internalist” models of operational situations, rather than the “externalist” ones said to be characteristic of scientific endeavor. It is difficult to imagine, however, how a uniquely internalist representation of a “conscious” or aware state can or could be useful: its existence would imply not only the usually-quoted criterion of lack of knowledge of the causes of received stimuli, but also the complete absence of any attempt to investigate or imagine the origins of those stimuli. To investigate in such a way requires the construction of an (imagined) externalist model of the situation: to not do so seems to imply lifelessness! Consequently, it makes more sense to describe living interactions as a negotiation between internalist and externalist representation, through a process which mirrors the internal-external negotiations which lie at the roots of human consciousness and moderated autonomy [8].

Human consciousness is “singular”, in that it only exists as an individual unified “entity”. It is within the “sufficient interpretation” and correlation of a multiplicity of informational details that *this* text *becomes* (nothing more… just “*becomes*” itself) within our consciousness. Its existence emerges from the process of integrative interpretation (or interpretive integration, if you prefer). This process, of the emergence of the informal from the formal (simplistically describable as emergence of the *analog* from the *digital*), is the very nature of living entities. It appears most obviously, but not uniquely, in the generation of analog protein folding from the digital code of DNA. Science does not merely *omit* this emergence from its confines; it *expels* it, as being too difficult to deal with. A lifelike nature is by definition external to a scientific development!

Cooperative Intelligent Systems

So, how are we to develop “lifelike” cooperative intelligent systems? Ultimately, not through uniquely digital computation, although this can provide effective interfacing between a central information processor and the outside world. This is itself the manner in which our own brains operate: a central *really* parallel processing style, whose operation is most closely related to the superposition-and-selection mechanisms of quantum mechanical interaction [9, 10], and integration and differentiation of the results of this processing to serve localized output and input nodes. Currently this style of integration and differentiation is far beyond our constructional capabilities, and while a prime target must be to investigate and

develop lifelike information integration, we can nevertheless achieve useful preliminary results if we couple our targets to the means which are available, so long as we do not fool ourselves into thinking that this will be sufficient.

Two routes (at least) present themselves for simulation of a desirable computational structure. One depends on the axonite mesh proposition of Karl Pribram [10], in which the outputs from a large number of sender-neurones are distributed in parallel as a quasi-wave to a large number of receptor-neurones, simulating the nonlocal distribution of solutions which characterizes quantum superposition, and storing the associated information in a distributed manner as a "collapse" of the wave at the receptor dendrites. This strong contender matches well with experiments carried out to define the neural location of consciousness [11]. The other route depends on the mathematical distribution of information across a large parallel processing network by the recursive integration of Dempster-Shafer probability into diffuse rationality [12]. It remains, however, difficult to see how either of these routes can provide a sufficiently "intelligent" information integration to generate any "real" consciousness in an artificial structure, and long-term hopes most probably rest with currently advancing projects which aim to introduce less-than-formal computation into the hardware elements of computer processing, rather than with the simulation of parallel processing via digital software.

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